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PRELIMINARY FLIGHT RESEARCH ON AN ALL-MOVABLE HORIZONTAL TAIL AS A LONGITUDINAL CONTROL FOR FLIGHT AT HIGH MACH NUMBERS

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PRELIMINARY FLIGHT RESEARCH ON AN ALL-MOVABLE HORIZONTAL TAIL AS A LONGITUDINAL CONTROL FOR FLIGHT AT HIGH MACH NUMBERS

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SUMMARY

The NACA is conducting flight tests of an all-movable horizontal tail installed on a Curtiss XP-42 airplane because of its possible advantages as a longitudinal control for flight at high Mach numbers. The results are presented for some preliminary tests in the low-speed range for which the tail was very closely balanced aerodynamically and a bobweight was used to obtain stable stick-force variations with speed and acceleration. For these tests, the tail was hinged at 0.24 chord and was tried with two arrangements of servotab control.

The elevator control was found to be unsatisfactory with the control arrangements tested. Although there were sufficient variation of stick force with acceleration in steady turns and a stable stick-force variation with speed, the near-zero variation of stick force with stick deflection resulted in an extremely sensitive control that required continuous attention in order to avoid motions of the airplane due to inadvertent movements of the control stick. For subsequent tests, the servotabs are being connected as geared unbalancing tabs in order that more conventional elevator hinge-moment characteristics may be obtained.

The expected advantages of the all-movable tail with a control system utilizing tabs would of course be limited to flight at Mach numbers below those for which severe compressibility effects are encountered on the tail itself. For higher Mach numbers, the all-movable tail would require an irreversible power-boost control in order to handle the large hinge-moment increases that are expected.

INTRODUCTION

The possible advantages of an all-movable horizontal tail for longitudinal control have been considered for some time. This type of tail recently has been suggested for flight at high Mach numbers since it offers a means of eliminating the pitching moments that result from the downwash changes which accompany compressibility effects on the wing when conventional fixed stabilizers are used. As a consequence, an all-movable horizontal tail was designed for the Curtiss XP-42 airplane (a modified P-36 airplane), and flight tests were made of the airplane with this tail installed. The XP-42 airplane cannot be flown at Mach numbers at which control difficulties ordinarily arise; however, speeds and accelerations that needed to be covered in a preliminary research program could be obtained.

With the all-movable horizontal tail installed on the XP-42 airplane, a series of ground handling tests and two flights have been made. In the two flights, the maneuvers were limited to low-acceleration turns and the speed was limited to 200 miles per hour. The present report summarizes the data obtained.

TAIL CHARACTERISTICS

The all-movable horizontal tail that was designed for the XP-42 airplane incorporates three distinguishing features:

(1) An all-movable tail plane (elevator) hinged at its aerodynamic center

(2) Servotab control

(3) A bobweight in the control system

A tail arrangement incorporating these features offers several advantages. When the tail plane is hinged at its aerodynamic center, the variations of hinge-moment coefficient with elevator angle C_{h_δ} and with angle of attack of the tail C_{h_α} are very near zero. The stick force required to produce a speed or acceleration change then depends only on the bobweight

effect; is independent of the tail load and the flow direction at the tail; and is therefore independent of airplane center-of-gravity position, power and flap effects (except for changes in dynamic pressure at the tail), altitude, and downwash changes that accompany Mach number effects on the wing. In addition, an all-movable horizontal tail provides a greater down load in the landing attitude than a conventional stabilizer and elevator. This characteristic permits an airplane to meet landing requirements for a greater center-of-gravity range or, for the same range, permits a reduction in tail area if more-forward center-of-gravity positions are used.

It was realized that compromises would probably be required as the tests progressed. From the beginning it was apparent that longitudinal oscillations might exist and that the pilot might move the tail to a position at which the tail load might be excessive before the airplane acceleration, and therefore the force from the bobweight, would be experienced.

Pertinent characteristics of the tail and its installation are shown in figures 1 to 3. The tail area was not reduced in comparison with the original tail area because moving the center of gravity of the airplane forward was not feasible. The aspect ratio was increased in comparison with the original tail to compensate for the shorter tail length that was required for installation purposes. The elevator was mass-balanced about its hinge line, and the servotabs were mass-overbalanced about their hinge lines to give dynamic balance for rotation of the elevator. The bobweight in the control system, which was located 7.0 feet behind the center of gravity, gave a force of 6 pounds at the pilot's grip.

Two arrangements of the servotab control system have been used to date. Schematic drawings of these systems are given in figure 4. In arrangement 1, a spring was incorporated on the servotabs to keep them from banging against their stops in ground handling tests. The spring did not alter essentially the condition of $C_{h_\alpha} = 0$ and $C_{h_\delta} = 0$ for this arrangement when the aerodynamic center was at the hinge line. After a few tests, the control system was changed to arrangement 2. In this arrangement, the point at which

the additional link was attached was so chosen that the tabs would deflect in the same direction as the elevator (unbalancing) in a ratio of tab angle to elevator angle $\frac{\delta_t}{\delta_e} = 1$ (no spring deflection). This arrangement made Ch_δ negative but permitted Ch_δ to approach zero as the speed increased, since the action of the spring reduces $\frac{\delta_t}{\delta_e}$ with increase in speed. This arrangement did not alter Ch_α and retained the servotab action of arrangement 1. In arrangement 2 the trim tabs were locked in the neutral position; trim changes were made by changing the servotab position. Arrangement 2, with spring added, is the geared unbalancing tab arrangement used to obtain a stable variation of rudder force with rudder deflection on two all-movable vertical tails previously tested at the Langley Laboratory (references 1 and 2).

TESTS AND RESULTS

With the elevator control system connected as in figure 4(a), the control felt uncertain to the pilot in taxi runs and ground flights (take-off, flight along runway, and landing). In an attempt to isolate the trouble, the servotabs were locked and taxi runs with the tail down were made at about 45 miles per hour with the elevator moved slowly through its deflection range. The data of figure 5(a) were obtained in a run of this type. The slope of the curves in figure 5(a) indicates that the aerodynamic center of the tail was between 3 and 4 percent of the mean aerodynamic chord ahead of the hinge line, an indication that the tail was overbalanced and that Ch_α was positive and not zero. The breaks in the curves at large down elevator deflections are the result of stalling of the tail. Since wind-tunnel tests have shown that strips on the trailing edge of an airfoil move the aerodynamic center rearward, this convenient method was used to bring the aerodynamic center to the elevator hinge line. Strips of different sizes were tried until the aerodynamic center was moved back to the hinge line (fig. 5(b)) by 0.28-inch strips attached outboard of the servotabs. No strips were attached to the trailing edges of the servotabs because the strips

would make the variation of servotab hinge-moment coefficient with angle of attack of the tail negative; this effect is similar to moving the aerodynamic center of the elevator forward.

With C_{h_α} and C_{h_δ} zero, the control still felt uncertain to the pilot and was unsatisfactory in ground flights. The uncertain feel of the controls probably resulted from the absence of stick forces associated with stick movement. The stick forces from accelerations (due to the bobweight) did not give significant feel to the pilot for these ground flights because the normal accelerations were small and lagged behind the stick movements too much at these low speeds. It was concluded that, in take-offs and landings in which rather large and rapid movements of the control stick are made, variation of stick force with stick deflection must be provided in order to give the control the feel necessary for the pilot to fly the airplane with assurance. The control system was therefore changed to arrangement 2; and, after satisfactory ground tests, two flights were made with this arrangement. For these flights, the airplane weight was 6100 pounds and the center of gravity was at 28.1 percent of the mean aerodynamic chord with wheels up. The longitudinal characteristics of the airplane were recorded in abrupt pull-ups, steady turns, and steady flight through the speed range. Records of stick-free oscillations were also obtained. The data of these flights are given in figures 6 to 8 and indicate that

(1) The airplane exhibited stick-free and stick-fixed static longitudinal stability

(2) The airplane would trim throughout the speed range tested

(3) There was a stick-force gradient in steady turns of about 8 pounds per g

(4) Stick-free oscillations at 115 and 157 miles per hour damped satisfactorily

Despite these satisfactory characteristics, the pilot considered the control sensitive and uncertain and therefore unsatisfactory. Continuous attention to the control was necessary in rough air in order to avoid motions of the airplane due to inadvertent movements of the control stick. In addition, the control

was considered sensitive because in abrupt maneuvers the reactions of the airplane were not proportional to the forces exerted by the pilot.

A comparison is made in figure 9 of data obtained during abrupt pull-ups made with the XP-42 airplane and a Curtiss P-40 airplane, for which the stick-force gradient in steady turns was also about 8 pounds per g. The curves of figure 9 show that the force required for the initial deflection of the all-movable horizontal tail was about 5 or 10 percent of the force required for the deflection of the P-40 elevator for approximately the same resulting normal acceleration. This comparison indicates that insufficient variation of stick force with stick deflection is the reason for the pilot's dissatisfaction with the control.

It is interesting to note here that, since these tests were made, the NACA pilots have expressed dissatisfaction with closely balanced elevators of conventional design on other airplanes because of the sensitivity of the control. In this connection, a theoretical investigation (reference 3) has been made of the effect of various hinge-moment parameters on elevator stick forces in rapid maneuvers.

SUBSEQUENT TESTS

For subsequent flight tests, the control system is being modified to incorporate preload in the servotab spring. With this arrangement conventional stick-force characteristics can be obtained, but the advantages that accrue from $C_{h_\delta} = 0$ of course cannot be realized. The possibility still exists of making the all-movable tail a satisfactory longitudinal control with $C_{h_\delta} = 0$. In this regard, provision has been made to incorporate a damper on the servotab spring. The damper would in effect eliminate the spring action from abrupt control deflections. Preload in the servotab spring will not destroy the expected advantage of the all-movable tail for flight at high Mach numbers, because the servotab will come into action when the stick force is sufficient to overcome the preload in the spring.

The use of an all-movable tail that depends on tab action is necessarily limited to flight at Mach numbers below those for which severe compressibility effects are encountered on the tail itself. For higher Mach numbers, the all-movable tail will require an irreversible power-boost control in order to handle the large hinge-moment increases that are expected. It appears that the development of such a power-boost control warrants consideration.

CONCLUDING REMARKS

In preliminary flight tests of an XP-42 airplane with an all-movable horizontal tail that incorporated very close aerodynamic balance and a bobweight, the elevator control was found to be unsatisfactory. There were sufficient variation of stick force with acceleration in steady turns and a stable stick-force variation with speed, but the control was sensitive and required continuous attention in order to avoid motions of the airplane due to inadvertent movements of the control stick. The unsatisfactory qualities of the control were attributed to insufficient variation of stick force with stick deflection, which resulted from the very close aerodynamic balance.

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2. Kleckner, Harold F.: Flight Tests of an All-Movable Vertical Tail on the Fairchild XR2K-1 Airplane. NACA ACR No. 3F26, 1943.

3. Jones, Robert T., and Greenberg, Harry: Effect of Hinge-Moment Parameters on Elevator Stick Forces in Rapid Maneuvers. NACA ARR No. L4J12, 1944.

Figure 1.- Three-quarter rear view of Curtiss XP-42 airplane with all-movable horizontal tail installed.

Figure 2.- Close-up of all-movable horizontal tail installed on Curtiss XP-42 airplane.

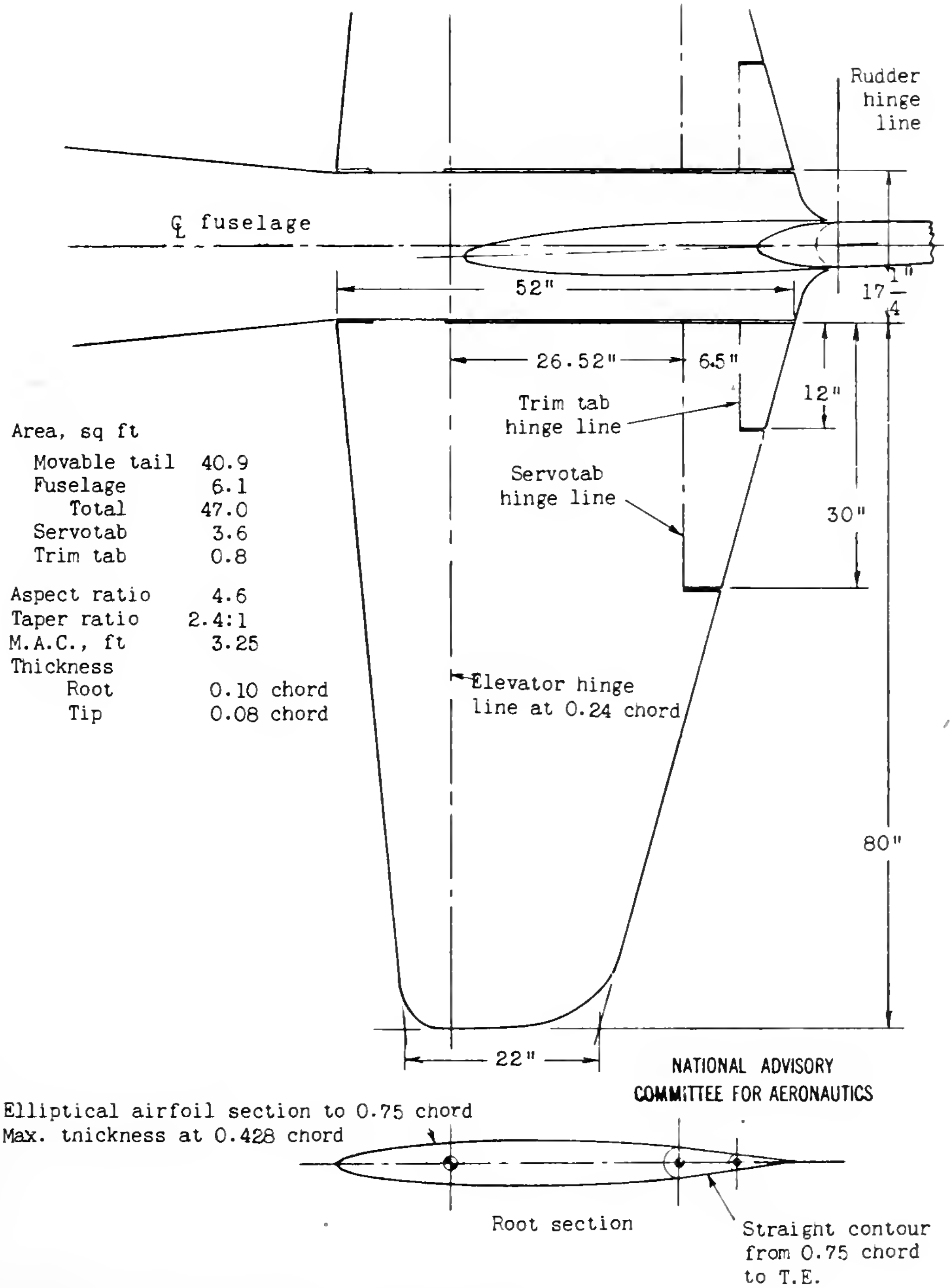


Figure 3.- Dimensions of all-movable horizontal tail for the Curtiss XP-42 airplane.

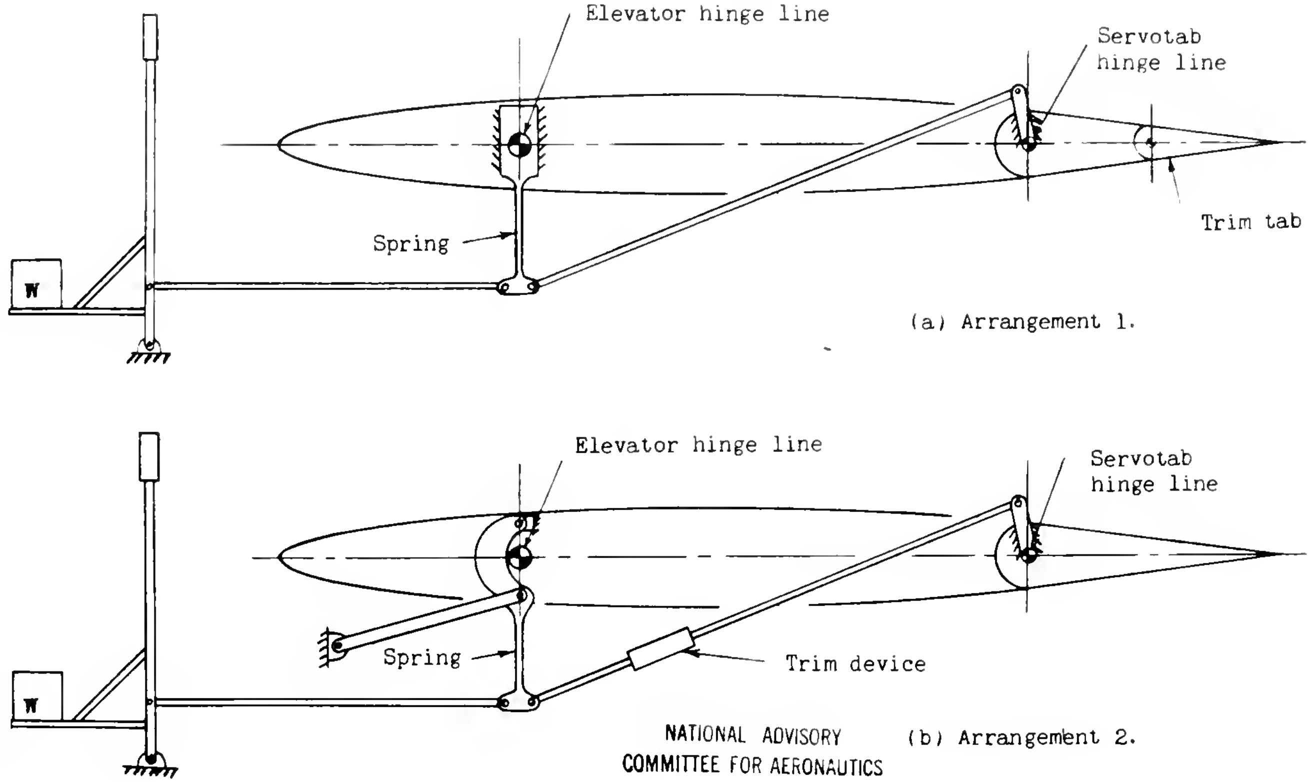
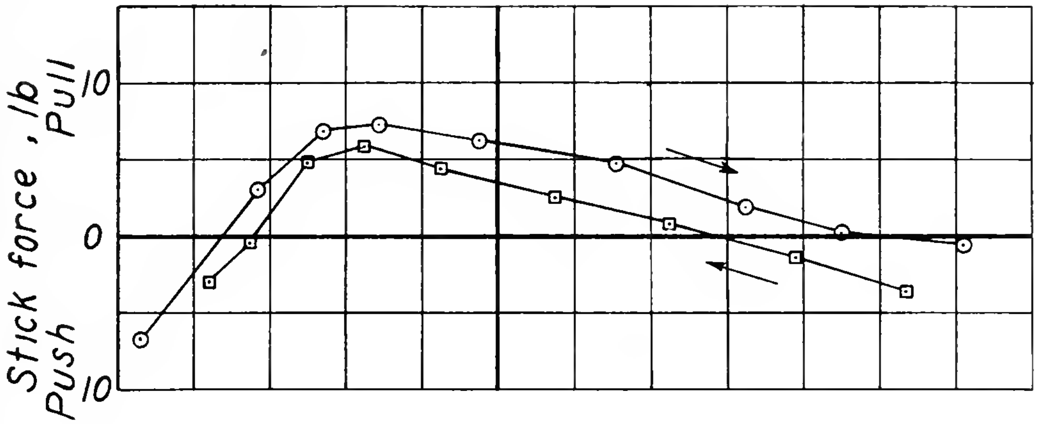
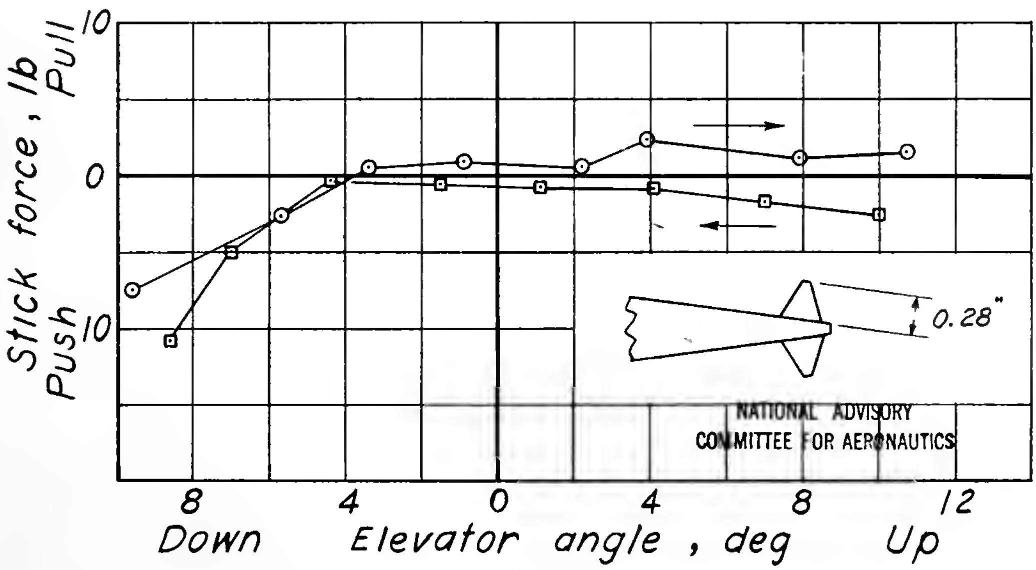


Figure 4.- Schematic sketch of control systems used with XP-42 all-movable horizontal tail. W, bobweight.



(a) Original trailing edge, no strips.



(b) Trailing edge equipped with 0.28-inch strips outboard of servotabs.

Figure 5.- Variation of stick force with elevator angle for steady elevator movements in taxi runs, three-point attitude. Curtiss XP-42 airplane with all-movable horizontal tail. Readings taken every $\frac{1}{2}$ second; arrows indicate direction of elevator motion.

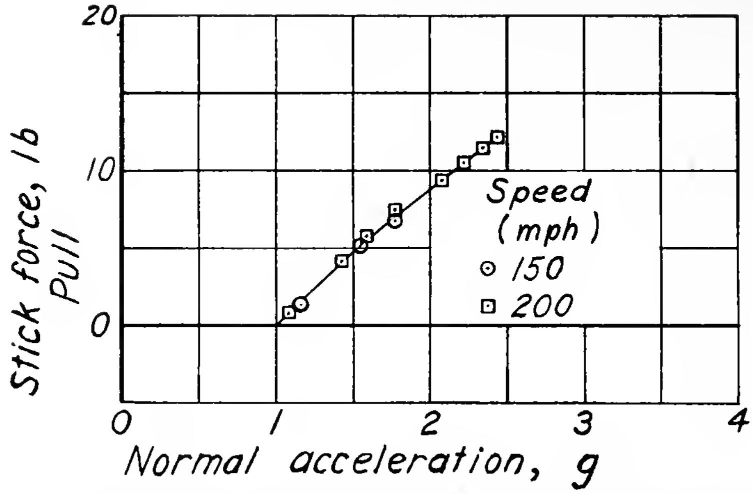


Figure 6.- Variation of stick force with normal acceleration in steady turns at an altitude of 5000 feet. Curtiss XP-42 airplane with all-movable horizontal tail; 6-pound bobweight in control system.

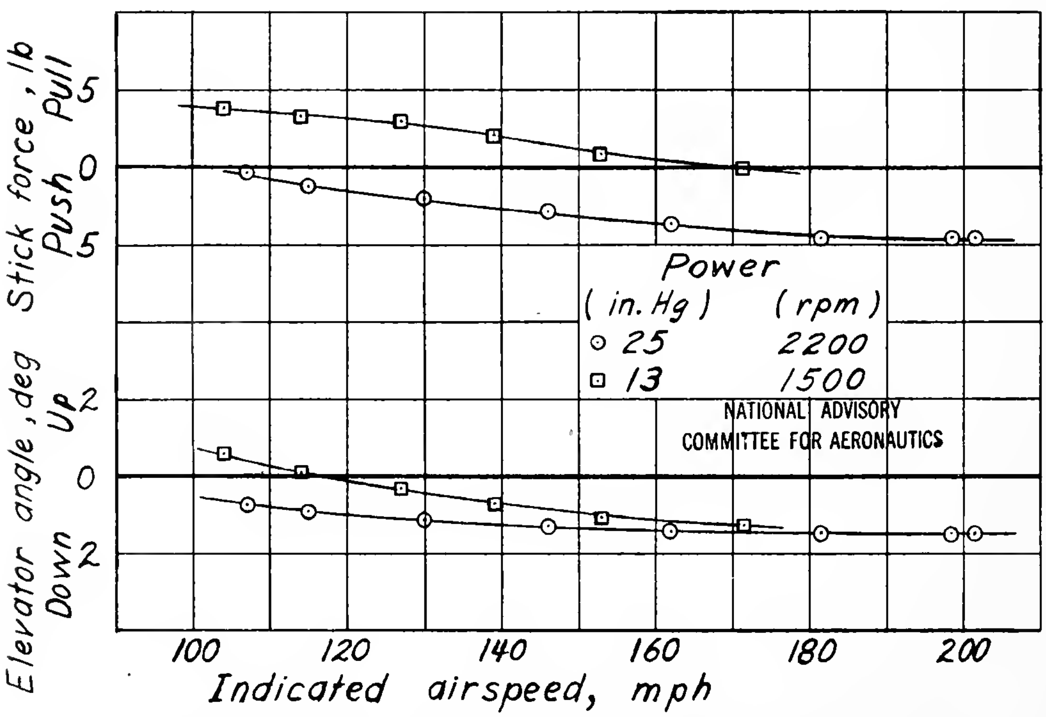
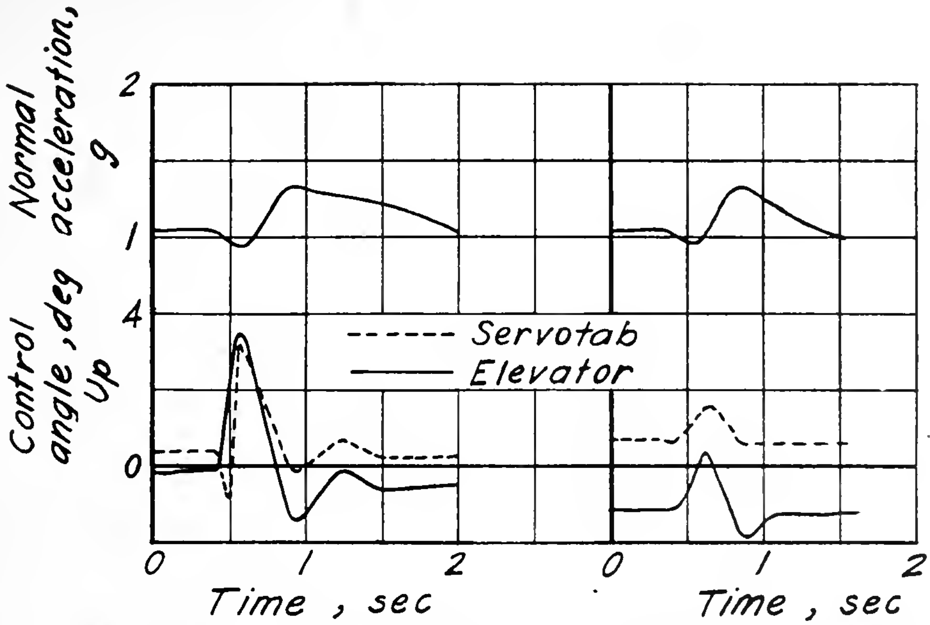


Figure 7.- Variation of stick force and elevator angle with indicated airspeed. Curtiss XP-42 airplane with all-movable horizontal tail.



(a) Speed, 115 miles per hour. (b) Speed, 157 miles per hour.

Figure 8.- Records of longitudinal oscillations made by abruptly moving and then releasing the stick. Curtiss XP-42 airplane with all-movable horizontal tail; no stick force available.

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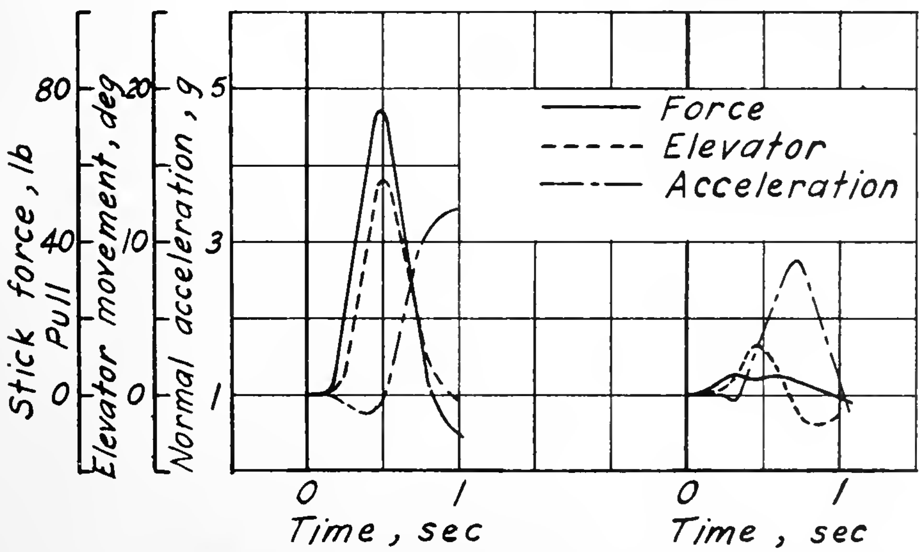

(a) P-40 airplane; speed, 188 miles per hour. (b) XP-42 airplane; speed, 205 miles per hour.

Figure 9.- Comparison of data obtained during abrupt pull-ups of Curtiss XP-42 airplane with all-movable horizontal tail and of Curtiss P-40 airplane.